Flexible 60-90W ArF light source for double patterning immersion lithography in high volume manufacturing

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ABSTRACT

The ability to extend deep ultraviolet (DUV) lithography into the 32 and sub-32nm domain has more recently relied on improvements in source-mask optimization (SMO), double patterning (DP) and complex, pixellated illumination patterns. Yet these techniques require a commensurate improvement in the light source that powers the latest generation scanners in order to enable high performance at high throughput. This paper will show detailed performance results of the latest-generation light source from Cymer that incorporates flexible power with dramatic improvements in dose, wavelength and bandwidth stability.

KEYWORDS: immersion lithography, double patterning, excimer laser, deep ultraviolet

1. INTRODUCTION

As ArF immersion lithography is extended to meet the demands of 32nm and below, the requirements from the light source have become progressively more stringent, in the areas of performance and operating cost. The ability to extend deep ultraviolet (DUV) lithography into the 32 and sub-32nm domain has more recently relied on improvements in source-mask optimization (SMO)[1], double patterning (DP) and complex, pixellated illumination patterns[2]. The scanner light source has been driven to more stable optical performance (energy, wavelength and bandwidth) as well as improved beam stability (pointing, divergence, symmetry and polarization) for these resolution enhancement technologies (RET) to be successful. Additionally, some of the aforementioned technologies can be further optimized with a flexible light source that is able to produce varying power levels to suit the specific application or layer in a cost-effective manner. In the area of operating costs, DP lithography has introduced a significant cost penalty in pursuing 32 and sub-32nm patterns, as those critical layers impose a significant throughput impact for the litho cell. Scanner designers have pushed on all fronts to enhance throughput, including stage speed increases and scan slit window reductions that demand increased power levels from the light source. In this paper, we will discuss how the latest-generation lithography light source from Cymer, the XLR 600ix (announced in February 2009[3]), has addressed these performance constraints while driving the operating costs down over time. Historically, the light source was limited to a narrow range of operating power, while improvements in optical performance were extracted. This led to the use of attenuating filters on the scanner to modulate light source power as needed, effectively 'throwing away' light. The wide power range of the XLR 600ix, from 60 to 90W, enables optimum power selection without waste. At the same time, significant performance improvements have been introduced on the XLR 600ix that reduce dose, wavelength and bandwidth variability, using sophisticated controls systems, enabling improved critical dimension (CD) uniformity and depth of focus control, while operating at higher scanner throughputs. The XLR 600ix includes technological improvements to extend parts lifetime and reliability, as well as operational improvements that deliver predictable costs via the Cymer OnPulse™ program. This paper will illustrate extremely stable light source performance over extended operating conditions in the areas of dose, wavelength, bandwidth and beam stability while operating at a high power, 90W regime. Some of the challenges that have been overcome to deliver this capability will be presented, such as advances in optical materials and coatings for improved lifetime and beam stability characteristics.

2. POWER FLEXIBILITY

The operating range of an excimer laser is typically confined to a narrow band as multiple performance characteristics have to be balanced to meet stringent optical requirements. Large variations in power can have detrimental effects to parameters such as bandwidth, wavelength and dose stability, as well as beam pointing parameters. The latter can be particularly affected by thermal transients that occur in the optics path of the laser,

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potentially distorting the beam profile and pointing characteristics. To meet this challenge, several technologies have been employed. In the areas of bandwidth, wavelength and dose stability, advanced algorithms that use closed-loop feedback of laser output as well as known relationships to duty cycle and energy to counteract performance excursions. This is possible due to fast and accurate on-board metrology as well as advanced control architectures that achieve extremely stable output performance.

In the area of power management, high variations in output power either as a function of duty cycle or average output energy can impose a highly varied thermal load on the system, especially in the laser optics. To minimize sensitivity to changes in average power, a significant, 2+ year effort was placed on developing advanced optics materials, coatings and thermal management technologies. The results are illustrated in Fig. 1, where various beam characteristics (y-axis) are shown as a function of rep rate changes (x-axis) while operating at 90W output power. Furthermore, the improved beam uniformity that is intrinsic to a recirculating ring architecture unique to the Cymer XLR series conspired to achieve extremely stable output characteristics as illustrated in Fig. 2, where peak energy density (the 'hottest' point in the beam's spatial domain), as well as the beam symmetry (centroid) are tested against a varying duty cycle at 90W.

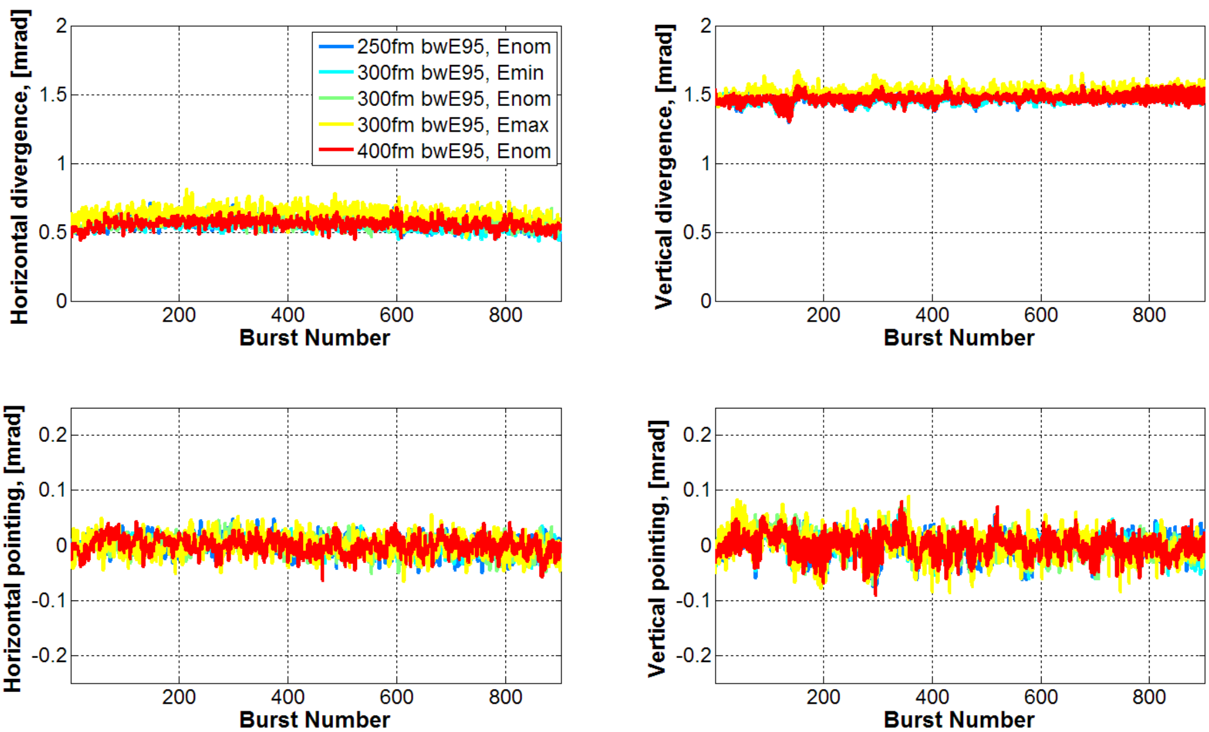

Figure 1 – Physical beam properties under various operating conditions (horizontal axis) and E95 bandwidth settings during 90W operation.

Lastly, with regards to high power operation, the XLR 600ix system is currently unique in the marketplace in its ability to deliver power at 90W, at high duty cycle operation (up to 75%). In addition to the above examples illustrating performance stability under these conditions, a vivid example of the high performance optics materials and coatings is shown in Fig. 3, where system output polarization is maintained at >99%. Output polarization can be heavily influenced by thermally induced optics birefringence, leading to a loss in polarization purity, and the data here is evidence that such a phenomenon is not present.

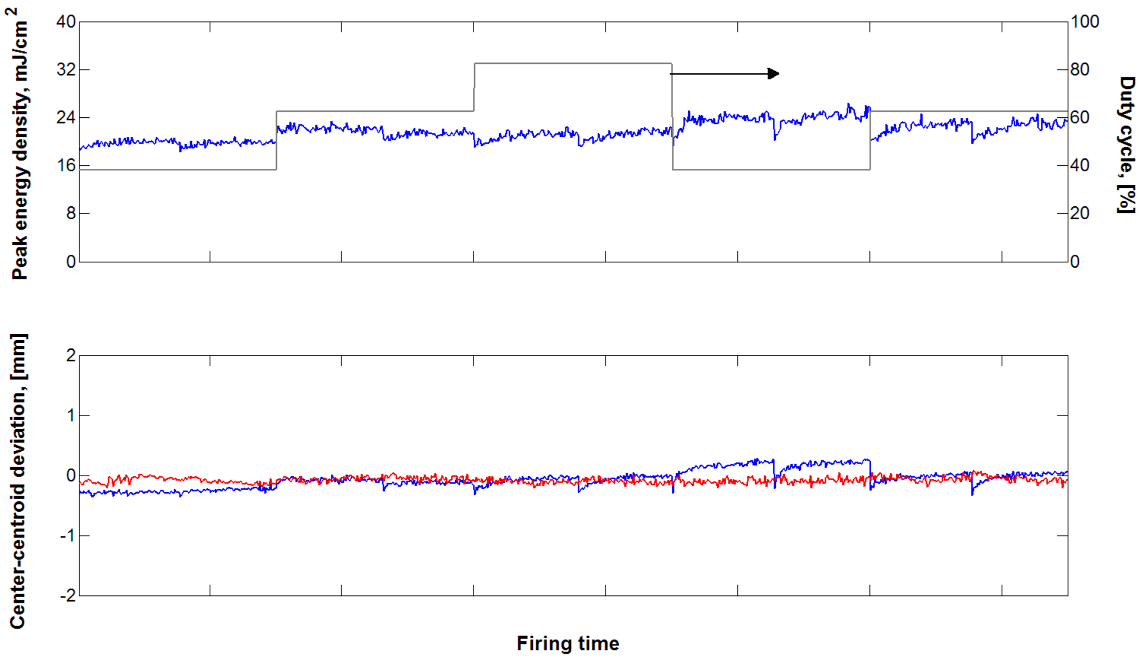

Figure 2 – Peak energy density at 90W (15mJ @6kHz) under various operating modes (duty cycles) showing performance well below the typical <35mJ/cm^2 scanner requirements (top) and beam symmetry under the same conditions (bottom).

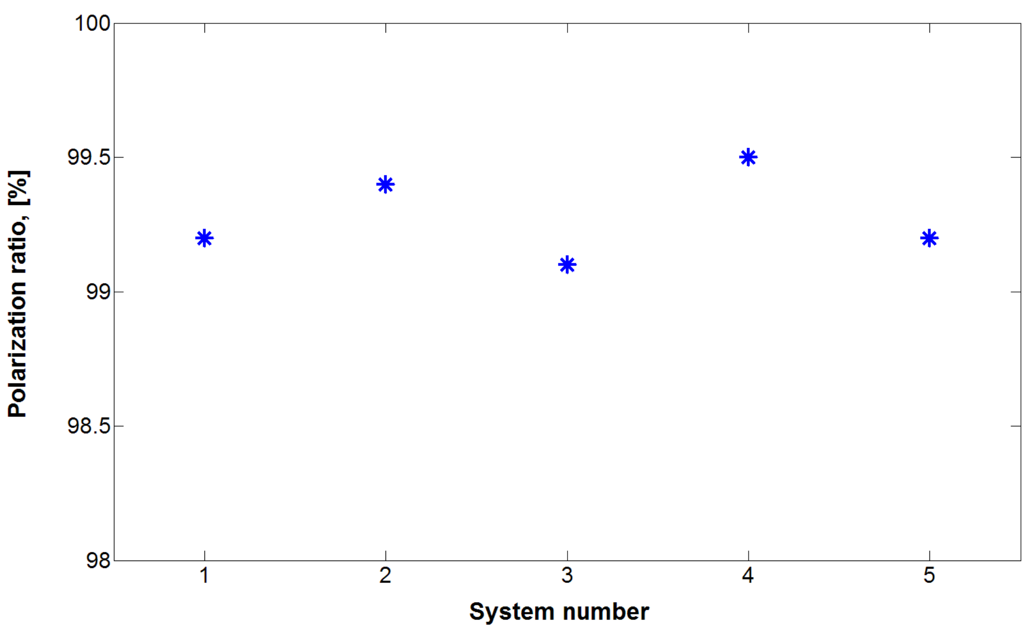

Figure 3 – System output polarization ratio for 5 lasers, operating at 90W (15mJ @6kHz). Testing is performed under a variety of operating conditions, spanning the entire operating range, with the lowest polarization value reported here.

3. ENERGY STABILITY

One of the light source attributes in lithography that has a direct impact on CD uniformity is the energy stability that translates to dose uniformity on the wafer. While designs can be optimized to achieve good stability under constant rep rate and duty cycle conditions, it is dramatically more challenging to maintain stability under varying conditions. A combination of passive solutions (system hardware design) and active solutions (real-time controls) are generally employed to address the entire operating range of the laser. In the XLR 600ix design, the recirculating ring architecture intrinsically lends itself to improved stability by ensuring that the power amplification stage is operating in a saturated state, thereby minimizing any fluctuations. However, to accommodate operating modes that require large changes in duty cycle, as well as output power, an active, closed-loop control system is employed to compensate for any transient behavior that would otherwise arise. The XLR 600ix employs the latest incarnation of high speed closed loop control, where pulse-to-pulse stability is controlled to extremely tight tolerances. This enables the use of higher scanning speeds on the scanner (with fewer pulses per slit) that in turn enable higher wafer throughput. Figure 4 shows an example of this performance where dose stability is plotted vs. varying duty cycle, rep rate and energy conditions that comprise a stress test, with a nominal output power of 90W.

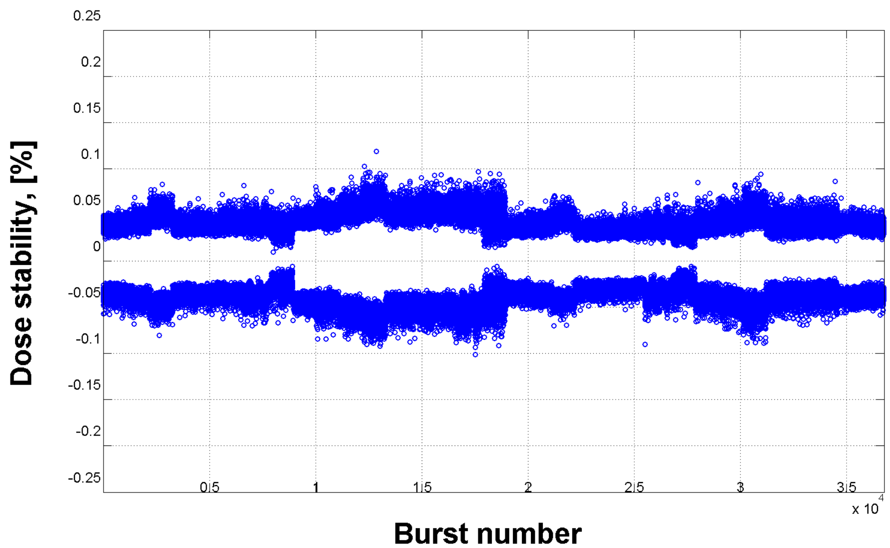

Figure 4 – Dose stability at 90W nominal power vs. time during a stress test that varies duty cycle, rep rate and energy targets.

4. WAVELENGTH STABILITY

The laser center wavelength stability is measured in terms of femtometers, and can directly or indirectly impact a number of lithography characteristics, such as focus, optical proximity correction (OPC) and overlay (lens aberrations, telecentricity). For these reasons, very high stability is sought. In addition to advancing the state of the art in system design for nominal high stability, active control is also required here to compensate for transient phenomena when operating conditions are varied. The XLR 600ix employs a high speed, closed-loop control system that suppresses variability as changes are made to duty cycle, energy and rep rate values that the scanner requires for wafer exposure. Figure 5 shows the characteristic wavelength stability achieved using the same stress tests employed for the earlier data above. Leading-edge immersion lithography requirements dictate a variation of no more than ±12fm from target in order to achieve the specified on-wafer performance characteristics in focus and overlay; the data here shows performance that far exceeds this requirement, showing ±6fm under most operating conditions, with extremes well below ±8fm.

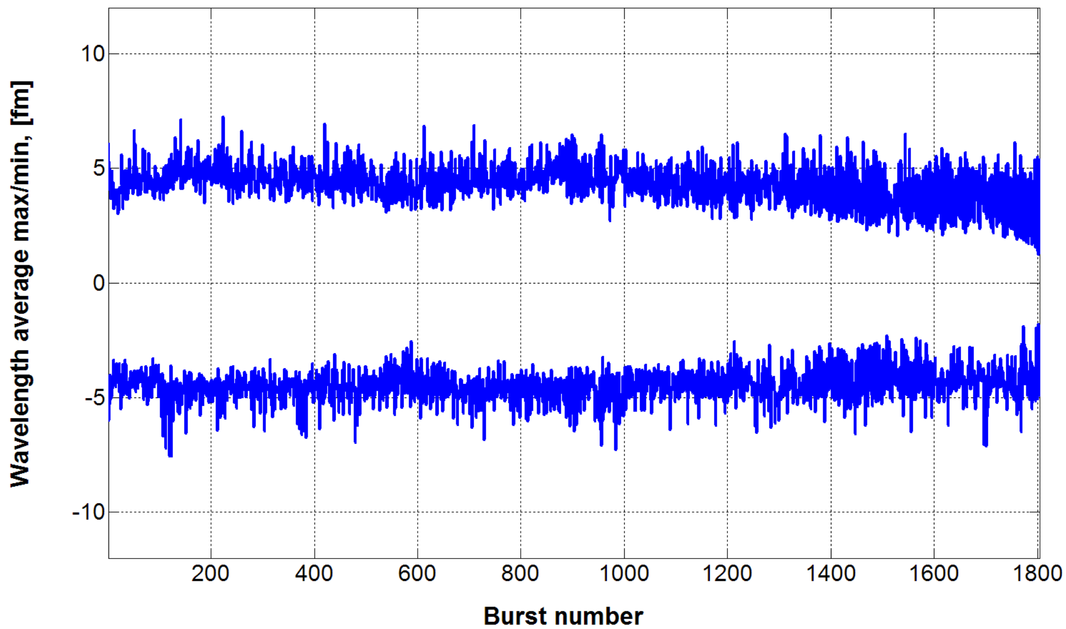

Figure 5 – Wavelength stability plotted as a maximum and minimum deviation from target across a stress test that includes duty cycle, rep rate and energy target variations, nominally operating at 90W.

5. BANDWIDTH STABILITY

The spectral characteristics of the light source define on wafer performance characteristics such as CD control and overlay, namely through their sensitivity to contrast. Furthermore, OPC models assume a certain value for bandwidth upon which OPC features are designed. Variations away from these modeled values can have a negative impact on resolution and CD uniformity, so the ability to achieve very stable bandwidth, *at the desired bandwidth target*, are very important. The XLR 600ix employs a powerful closed loop control system that not only achieves extremely stable bandwidth at a given target, but allows for a user-defined bandwidth target to be set to match the OPC requirements for the reticles that are being printed. Figure 6 shows data across the stress test with several bandwidth targets, all indicating extremely stable performance independent of bandwidth setting. Another application of user-settable bandwidth is the ability to match multiple systems in a fab environment to achieve identical performance.

5.1 Bandwidth Tuning

Another important attribute of such fast closed-loop control is the ability to modulate bandwidth targets very quickly, as illustrated in Fig. 7. In this example, each data cluster represents a single field or die exposure, and shows how it is possible to modulate bandwidth in a die-to-die fashion. This opens up another dimension in flexibility and can be used to compensate for center-to-edge wafer variations, for example.

6. SUMMARY

As 193nm immersion lithography is further challenged with double patterning applications, stringent demands are placed on the light source to enable improved CD uniformity, overlay and OPC performance. The XLR 600ix light source described here exceeds these requirements and further enhances the lithographer's toolbox by providing flexibility in power output as well as bandwidth target. This added flexibility is achieved while continuing to provide leading-edge optical performance characteristics, through the use of a unique laser architecture, hardware design and advanced control systems.

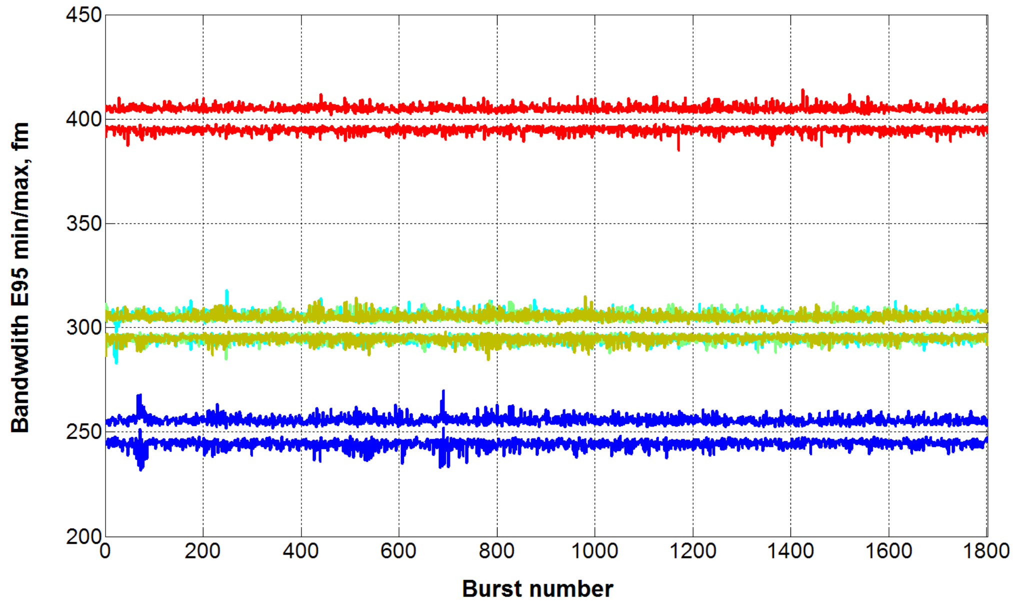

Figure 6 – Bandwidth stability (E95) at 3 different bandwidth settings (user defined): 250fm, 300fm and 400fm. The data represents maximum and minimum values during the stress test for each setting.

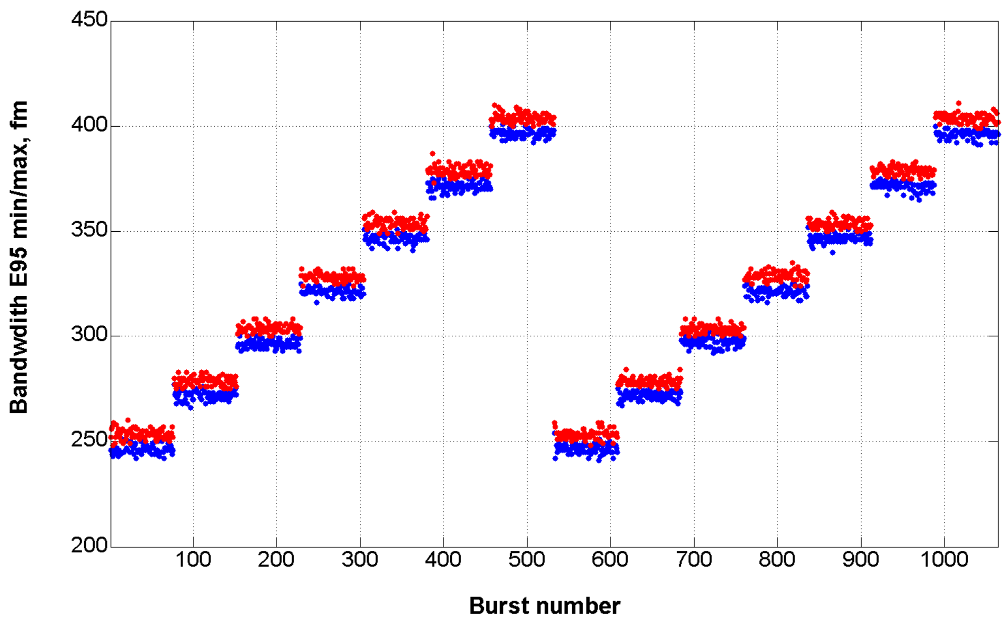

Figure 7 – Fast bandwidth tuning demonstration, showing exposure bursts representative of individual die exposures. In this demonstration, the bandwidth target is changed in 25fm increments from 250fm to 400fm and the cycle is repeated. The two colors represent maximum and minimum E95 bandwidth values as measured using on-board metrology.

[1]Matsuyama, T., Nakashima, T., Noda, T., “A study of source and mask optimization for ArF scanners,” Proc. SPIE 7274 (2009)

[2]Lai, K., Rosenbluth, A. E., Bagheri, S., Hoffnagle, J. A., Tian, K., Melville, D. O., Tirapu-Azpiroz, J., Fakhry, M., Kim, Y., Halle, S. D., McIntyre, G., Burr, G. W., Burkhardt, M., Corliss, D. A., Flagello, D. G., Zimmermann, J., Kneer, B., Rohmund, F., Hartung, F., Russ, C., Maul, M., Kazinczi, C. R., Engelen, A., Mulder, M., “Experimental result and simulation analysis for the use of pixelated illumination from source mask optimization for 22-nm logic lithography process”, Proc. SPIE 7274 (2009).

[3] Rokitski, R., Fleurov, V., Bergstedt, R., Ye, H., Rafac, R., Jacques, R., Trintchouk, F., Ishihara, T., Rao, R., Cacouris, T., Brown, D., Partlo, W., “Enabling High Volume Manufacturing of Double Patterning Immersion Lithography with the XLR 600i ArF Light Source”, Proc. SPIE 7274 (2009).